# DEVELOPMENT AND TESTING OF OVENS USING SAWDUST AS FUEL

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## ABSTRACT

In an effort to utilize agricultural residues produced in the forest industry in Sierra Leone, several studies have been carried out and reported in the literature on a simple method of burning sawdust. The work reported in this paper concerns the use of the "hole-through-sawdust" type burner to provide the heat required in ovens for baking.

A prototype oven has been developed and lab tested under various conditions, determined by the number of burner holes used and the height of the packed fuel. Temperature variation and the rate of consumption have been studied and the burner performance has been compared to the design equations used. Four models of the oven were field tested to obtain socio-economic data on user reaction and its potential for future use.

Results indicate that the oven produces temperatures comparable to standard electric and gas settings by appropriate loading of the sawdust burner. Also, the oven can maintain these ranges of temperatures to enable baking to be carried out. The data also indicates that the amount of sawdust used for each loading ranges between 2 to 4 kg and the fuel consumption rate cannot be effectively adjusted by the use of inlet flaps to vary the amount of combustion air.

Results of field trials carried out in four homes are positive. The oven has been generally accepted but efforts must be made to reduce the amount of smoke produced. It is noted that the oven may be very useful to people who bake cake at home for daily distribution to institutions. In such applications, the study shows that there is substantial savings in the cost of fuel, compared to gas and electricity operated ovens. The oven's cost is less than one-fourth the cost of electric and gas ovens.



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# 1. INTRODUCTION

## 1.1. Background

The search for and use of alternative forms of energy has in the past years been a major preoccupation of many countries in Africa. This has been prompted by; the high cost of conventional fuels, the generally high global rates of inflation, increase in energy demand and many other factors. Countries such as Sierra Leone have therefore made efforts to combat the situation by examining the potential use of several available sources.

## 1.2. Energy Availability and Use for Baking

Deposit of conventional sources of energy such as coal and crude oil have not been shown to exist in any exploitable quantities in Sierra Leone. Some deposits of lignite have been studied but its high sulfur content makes it a low grade fuel, which raises several question concerning the economics of its exploitation.

Electricity is generated mainly by imported fuel oil. A great potential however exists for hydro-electricity from a maximum possible installed capacity of about 650 MW. A hydro-electric project rated at about 35 MW is in progress. The unit cost of electricity is quite high and there is no indication that it will be affordable by many households in the near future.

A potential source of fuel is biomass in its various forms. A survey of the available forestry and agricultural waste, excluding fuel wood, is presently being conducted by Massaquoi (1985), from which preliminary data indicates an annual energy of 300,000 tonnes of oil equivalent can be obtained. This potential is quite significant considering that the total amount of imported crude oil is about 360,000 tonnes/annum.

## 1.3. Energy for Baking

It has been estimated by Davidson (1983) that the energy consumed in industrial baking is about 42.4 x $10^9$ kJ/annum, about 40 x $10^9$ kJ/annum being supplied by fuel wood. There is however no available data on home consumption of energy for baking, although such energy is supplied mainly by electricity and gas.

A material which could be used to generate heat for baking is sawdust. Its application in sawdust ovens has been studied and is presented in this paper.

### 1.4. Work Done on Use of Sawdust

The amount of sawdust available in Sierra Leone is about 2000 $m^3$/month, Bassey (1980). In the same study, detailed work on its heating values has shown that the calorific value of the fuel depends on moisture content and the species of tree from which the sawdust is obtained. A generalized equation however has a calorific value of about 16000 kJ/kg at a moisture content of about 20 % (dry basis), which corresponds to open air drying under local conditions.

A method of burning sawdust in "hole-through sawdust burners" has been extensively studied by Bassey (1977, 1983). This burner, shown in Fig. 1, has a non-combustible outer casing in which sawdust is packed to a height H. A hole, diameter d, is allowed to burn, using air which enters through the air inlet hole (diameter $D_B$). Equations for designing burners for various uses have been developed and are in the form,

$$d/D_B = C_1 \exp (C_2 t) \qquad (1)$$

$$m_f/tH = C_3 \exp (C_4 D_B) \qquad (2)$$

where,

$m_f$ = mass of sawdust consumed in t minutes in gm

$d$, $D_B$ = burner hole and air inlet hole diameters in cm

$C_1$, $C_2$, $C_3$, $C_4$ = Constants.

These generalized equations have been used succesfully in designing burners for various equipment such as, a crop dryer, cooker, water heater and fish smoker/dryer, Bassey (1983).

### 1.5. Aim of Paper and Methodology

The purchase of this article is to present work done on the design, development and testing of two prototype ovens using sawdust as a fuel in "hole-through-sawdust" burners. Also reported are the practical application of the results in household baking.

The work consisted of designing a first prototype and testing it in the laboratory. Based on the results obtained, improvements were made and further tests were carried out to compare both prototypes. Four of the second prototype were then placed in households, to obtain socio-economic data on their performance and acceptability.

## 2. DESIGN DETAILS OF OVEN USED

### 2.1. Design of Burner

The burner consisted of a container having a base area 40 x 40 $cm^2$ and 20 cm high, made of 0.06 cm thick galvanized iron sheet metal. Nine holes, 2 cm in diameter, and situated about 10 cm between centres, were drilled on the base of the container and served as the air inlet holes. This configuration was adopted, based on work already mentioned in section 1.4 and ensured the design of an oven having a size comparable to existing electric or gas ones. The design also ensured a burning time of more than two hours.

Charging of the burner was done by placing cylindrical rods, with diameters slightly less than $D_B$, through the holes and packing the sawdust around them tightly by hand.

The rods were then carefully withdrawn leaving vertical holes through the sawdust which were then lit to produce the heat. The burner could thus use N burner holes, ranging from 1 to 9, depending on the amount of heat needed.

### 2.2. Description of Prototypes I and II

The overall view of prototype I is shown in Fig. 2. It was made from 0.06 cm thick galvanized iron plate with double walls between which was placed 5 cm thick fibreglass wool insulation. An ash tray was situated below the burner and the door was insulated. Fig. 3 shows the cross sectional view of the oven. It is noted that the chimney passes through the baking space, causing exhaust gases to also heat up this space. Upper and lower oven spaces are created by a removable shelf made of galvanized iron sheet.

In order to shield the oven space from the burner compartment, an air gap (8 cm thick) sandwiched between two plates was created as shown in Fig. 3. Air entered the burner through the flap opening.

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Fig. 4 gives the relative dimensions of various components of the oven. the chimney was 60 cm long and 8 cm in diameter. Dimensions of the oven space was about 40 x 40 x 30 cm3. Prototype II was identical to prototype I, the only difference being that the bottom plate sandwiching the air gap between the burner and oven space was removed. Hot gases thus came into direct contact with the bottom of the plate separating the burner area from the baking space. As in the case for prototype I, the hot gases from the burner passed into the chimney without coming into direct contact with the oven space.

## 2.3. Instrumentation

In order to measure temperatures during the laboratory experiments, chromel-alumel (type K) thermocouples were connected to a Thermo Electric digital electronic temperature indicator, ELPH 4 model. The thermocouples were located at five points in either prototype I or II, as shown in Fig. 4.

During tests the ovens were placed on a scale so as to measure the decrease in mass of the fuel due to combustion.

# 3. EXPERIMENTAL PROCEDURE

The first set of experiments were done using prototype I. In these tests, the burner having air inlet hole diameters equal to 2 cm was loaded as described in section 2.1, to a height H using 7 burner holes. All packing of the sawdust was by hand. The whole burner was weighed and the holes were then lit by burning paper or wood shavings in the holes. When the holes started to glow uniformly throughout their heights, the burner was placed in the oven and the whole equipment weighed.

Temperatures and the weight of the oven were recorded at interval between 5 and 15 minutes until the completion of burning of the sawdust, which was indicated by a temperature drop in the combustion chamber and reduction in smoke from the chimney.

Several tests were carried out for oven I using N=7, $D_B$=2 cm and H=8, 10, 12 and 14 cm. In most of these experiments, the damper was fully open but some tests were carried out with the damper being 1/2, and 1/8 open.

The above procedure was adopted for tests with oven II. In these experiments, the parameters used were N=5 or 7, $D_B$=2 cm and H=6, 8, 10, 12 cm and the damper was fully open.

All the sawdust used during the tests had a moisture content of 23 % (dry basis), and a density of packing of about 200 kg/m3 was maintained during the experiments.

## 4. RESULTS AND DISCUSSION

### 4.1. Relative Temperatures in Oven I

The amount of heat transfered from the combustion chamber to the oven space depends on the relative magnitudes of temperatures. Typical temperature variation with time are shown in Fig. 5, and in Fig. 6 for H=12 cm and N=7.

It is noted that temperatures of the hot gases in the burner chamber attain maximum values around 300-320 °C as shown in Figs 5 and 6. Temperatures in the oven spaces are up to 150 °C and are lower than those in the burner chamber. Due to the metal shelf separating the lower and upper oven spaces, the lower space is up to 40 °C higher. Temperatures in the chimney, shown in Fig. 5, are generally higher than those in the oven space but drop below the values for the lower oven space as a result of heat losses during the final stages of combustion of the fuel. The ability of the oven to conserve useful heat in the baking space is indicated by this comparison.

Temperatures in the oven door typically range between 30 to 100 °C during the operation of the oven.

### 4.2. Effect of Height of Packing on Temperatures in Oven I

Results showing the effects of increasing the height of packing on the temporal variation of temperatures are shown in Figs. 7, 8 and 9 for H=10, 12 and 14 cm.

Combustion chamber temperatures shown in Fig. 7 are dependent on the value of H but it is noted that the maximum temperature does not exceed 400 °C. Similar trends are observed for the lower oven space temperatures shown in Fig. 8, where working temperatures of about 160 °C are possible after 40 to 180 minutes depending on the height of packing.

Temperatures in the upper oven space (Fig. 9) also depend strongly on the value of H but they are substantially lower. These results and those in Fig. 8 indicate that the shelf can be useful for baking foodstuff requiring different temperatures at the same time.

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An overall appreciation of the performance of the oven under various values of H is shown in table 1.

Table 1. Data for Oven I for Various Values of Height of Packing, H ($D_B$ = 2 cm, N = 7)

| H, cm | Tmax Combustion Chamber °C | Tmax Upper Space °C | Tmax Lower Oven | | Tmax Range for Lower Space | | |
|---|---|---|---|---|---|---|---|
| | | | °C | Time taken to attain, min. | °C | Time taken to attain, min. | Time spent in range, min. |
| 8 | - | - | 155 | 150 | 150-155 | 90 | 50 |
| 10 | 277 | 166 | 195 | 146 | 190-195 | 98 | 45 |
| 12 | 311 | 185 | 218 | 116 | 213-218 | 115 | 39 |
| 14 | 394 | 223 | 262 | 112 | 257-262 | 110 | 42 |

In order to specify operating temperatures, and cognisant of the fact that constant temperatures cannot be maintained, results obtained have been used to obtain Table 1. It is noted that the maximum temperature of the lower space ranges from 155 to 262 °C, depending on the value of H. During baking it is necessary to maintain a relatively constant value. It is assumed in this work that a range of temperatures, 5 °C below the maximum temperature of the lower space, is a working range of temperatures. These results, and the time taken to attain the range of values are shown in Table 1.

It is observed that the times taken to reach the maximum range of temperatures are not unrealistic. Noting that oven I had an air space sandwiched between two galvanized iron plates, temperatures in the baking space can be increased by removing the plate immediately above the burner.

4.3. Consumption of Sawdust in Oven I

The amounts of sawdust used in the burner during various tests are shown in Table 2.

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Table 2. Capacity of Burner Under Various Conditions ($D_B$ = 2 cm, N = 7)

| Height of Sawdust H, cm | Mass of Sawdust kg | Density of Loading kg/m3 |
|---|---|---|
| 8 | 2.43 | 200 |
| 10 | 3.06 | 199 |
| 12 | 3.57 | 194 |
| 14 | 4.42 | 205 |

Results for the variation of mass of sawdust used with time are shown for oven I in Fig. 10. The linear variation of $M_f$ is consistent with results of Bassey (1983).

For the burner with N=7, $D_B$=2 cm, the equation suggested by Bassey (1983) for the consumption of sawdust is

$$M_f/H = 2.05\ t \tag{3}$$

Using the results in Fig. 10, an equation obtained using the mean values of the slopes for the burner is

$$M_f/H = 1.47\ t \tag{4}$$

Eqn. 4 gives sawdust consumption about 28 % lower than the recommended equation. This is possible as the oven has more flow resistances causing a slower combustion of the sawdust compared to the open burner used by Bassey (1983), in which the only flow resistance was due to the air inlet, $D_B$.

4.4. Temperature Control in Oven I

The effect of adjusting the air inlet flap was investigated and results are shown in Figs. 11 (a) and (b). Results for the burner and the lower space temperatures immediately indicate that the adjustment of the flap has effectively no influence on their magnitudes. The inlet flap therefore does not serve any significant purpose.

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The nature of the packed bed burner makes it difficult to control its burning rate by using flaps. It is proposed that control of temperatures should be achieved by a variation of H and N.

4.5. Development of Oven II

Detailed testing of oven I, and results already discussed, clearly showed that the galvanized plate between the gap and the burner (see Fig. 3) might not be necessary as the temperatures, both in the combustion chamber and in the oven space, were not excessive. A second oven was therefore constructed and tested as mentioned earlier, with the modifications described in section 2.2. The flap was left fully open during all tests.

4.6. Performance of Oven II

Oven temperatures in oven II are shown in Fig. 12 for N=7 and H=6, 10 and 12 cm. These results are similar to those discussed for oven I, the difference being that the temperatures in oven II are higher.

Typical comparisons between the oven temperatures and the amount of fuel used are shown in Figs. 13 (a) and (b), and in Table 3 for the maximum temperatures.

Table 3. Comparison of Maximum Temperatures for Ovens I and II for Various Operating Conditions. ($D_B$ = 2 cm, N = 7)

| Oven | Height of Packing H, cm | Maximum Temperature in Oven | | | |
|---|---|---|---|---|---|
| | | °C | Tmax Range | Time taken to attain, min. | Time spent in range, min. |
| I | 8 | 156 | 151-156 | 130 | 55 |
| II | 8 | 176 | 171-176 | 95 | 30 |
| I | 10 | 195 | 190-195 | 146 | 45 |
| II | 10 | 213 | 208-213 | 100 | 46 |
| I | 12 | 218 | 213-218 | 116 | 39 |
| II | 12 | 250 | 245-250 | 135 | 40 |

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Temperatures are up to 40 °C higher in oven I compared to oven II. These higher values are related to the fact that the removal of the plate above the burner permits the hot gas to come into direct contact with the bottom surface of the base of the oven space. Another factor for the higher temperatures in oven II is due to the observed slight increase in mass of fuel consumed with time as shown in Fig. 13 (b).

Such an increase in fuel used may be due to the higher combustion air admitted as a result of taking off the plate above the burner. This may result in less restriction to the flow, hence the higher consumption of the mass of fuel.

Performance data for oven II, similar to those for oven I in Table 1, are shown in Table 4.

Table 4. Maximum Temperatures for Oven II for Various Values of Height of Packing, H ($D_B$ = 2 cm)

| Height of Packing, H, cm | N° of Holes N | Maximum Temperature in Oven | | | |
|---|---|---|---|---|---|
| | | °C | Tmax range °C | Time taken to attain, min. | Time spent in range, min. |
| 6 | 5 | 156 | 151-156 | 130 | 45 |
| 6 | 7 | 169 | 164-169 | 100 | 35 |
| 8 | 5 | 162 | 157-162 | 100 | 25 |
| 8 | 7 | 176 | 171-176 | 85 | 35 |
| 10 | 5 | 200 | 195-200 | 105 | 40 |
| 10 | 7 | 213 | 208-213 | 73 | 46 |
| 12 | 5 | 210 | 205-210 | 105 | 50 |
| 12 | 7 | 250 | 245-250 | 135 | 40 |

The maximum temperatures and the times taken to attain them are quite encouraging. There is clearly a possibility of controlling the temperatures by a combination of H and N.

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## 5. UTILIZATION OF RESULTS

### 5.1. Baking Temperatures and Equivalent Settings

The design of the ovens discussed above indicate that oven II performs better than oven I. It now remains to relate the result obtained to real-life baking conditions.

In order to compare the results to standard gas and electric ovens, the data are shown in Table 5 compared to these oven settings.

Table 5. Equivalent Settings Between Gas, Electric and Sawdust Oven II

| Temperature Description | Electric Oven | Gas Thermostat | Oven II | |
|---|---|---|---|---|
| | | | H, cm | N |
| Very Cool | 110 °C/225 °F<br>120 °C/250 °F<br>140 °C/275 °F | 1/4 - mark<br>1/2 - mark<br>1 - mark | | |
| Cool | 150 °C/300 °F | 1-2 - mark | 6 | 5 |
| Warm | 160 °C/325 °F | 3 - mark | 8<br>or 6 | 6<br>7 |
| Moderate | 180 °C/350 °F | 4 - mark | 8 | 7 |
| Fairly Hot | 190 °C/375 °F<br>200 °C/400 °F | 5 - mark<br>6 - mark | 10<br>10 | 5<br>5 |
| Hot | 220 °C/425 °F | 7 - mark | 10 | 7 |
| Very Hot | 230 °C/450 °F<br>240 °C/475 °F | 8 - mark<br>9 - mark | 12<br>12 | 5<br>7 |

With the exception of the very cool range of temperatures for which data were not available, it is noted that Table 5 gives combinations of H and N which produces working temperatures equivalent to those in gas and electric ovens. The user can thus use these results for operating oven II under real conditions.

### 5.2. Use of Oven II for Baking Cakes

There are many households where cakes are baked, on a daily basis using gas, for sale in various supermarkets, and institutions. In this case, it is considered useful to give guidelines for such baking activities. Table 6 gives burner configurations corresponding to recommended temperatures for baking a list of cakes.

Table 6. Burner Configurations for Baking Cakes in Oven II

| Type of Cake | Burner for Oven | | Time to wait before baking min. | Baking time | Comments |
|---|---|---|---|---|---|
| | H, cm | N | | | |
| Plain Cakes: | | | | | |
| Small | 10 | 7 | 75 | 15-20 | - |
| Large | 8 | 7 | 85 | 25 | not recommended for cakes larger than 0.25 kg. |
| Rich Cakes: | | | | | |
| Small | 10 | 5 | 105 | 15-20 | - |
| Large (e.g. fruit) | 8 | 7 | 85 | 25 | not recommended for cakes larger than (1/4 lb) 0.125 kg. |
| Sponge Cakes: | | | | | |
| Large | 8 | 7 | 85 | 25 | " |
| Sandwich | 10 | 7 | 75 | 9-12 | - |
| Biscuits/ Cookies | 8 | 7 | 85 | 25 | - |

## 6. FIELD TRIALS OF SAWDUST OVEN

### 6.1. Methodology Adopted

In order to obtain some socio-economic information for the developed oven, a limited number of field trials were conducted.

Four families were chosen and given the oven with several sacks of sawdust. Detailed instructions were also given on the operation of the ovens and on the adjustment of maximum attainable temperatures by a combination of H and N. The trials were carried out over a two week period at the end of which, each participant was requested to complete a questionnaire. Frequent visits were made to the households during the field trials to help with any problems.

The following were the information on the background of each participant according to number:

1. Commercial user; daily baking; used gas oven costing 3000 Leones; had an energy problem; monthly fuel cost 30 Leones.

2. Commercial user; daily baking; use charcoal/wood; wood oven costs Le50; no fuel problem; monthly fuel cost Le32.

3. Domestic user (household of 10); baking once a week; electric oven costing Le3000; energy problem; monthly cost Le10.

4. Commercial; baking once a week; electrical oven costing Le3000; energy problem; monthly cost Le15.

## 6.2. Results of Field Trials

The individuals involved with commercial baking used domestic ovens for baking small cakes and cookies for schools and other institutions. All of the participants used conventional gas or electric ovens except one who used wood in a crude oven consisting of a closed container heated over a three-stone-open-fire stove.

Responses to several questions were:

### Oven operation

| | | | |
|---|---|---|---|
| (a) | Is burner difficult to load? | Yes (0); | No (4) |
| (b) | Does lighting of burner take too long? | Yes (1); | No (3) |
| (c) | Is operation of oven messy? | Yes (2); | No (2) |
| (d) | Is smoke excessive? | Yes (4); | No (0) |
| (e) | Is the ash a problem? | Yes (0); | No (4) |

### Baking time and temperature

| | | | |
|---|---|---|---|
| (f) | Is warming up time too long | Yes (4); | No (0) |
| (g) | Does oven cool down too quickly | Yes (0); | No (4) |
| (h) | Is oven temperature too high | Yes (0); | No (4) |
| (i) | Is oven temperature too low | Yes (0); | No (4) |

### Cake quality

| | | | |
|---|---|---|---|
| (j) | Does product rise well? | Yes (4); | No (0) |
| (k) | Does product taste well? | Yes (4); | No (0) |
| (l) | Does product smell of smoke? | Yes (0); | No (4) |
| (m) | Did product get burnt? | Yes (4); | No (0) |
| (n) | Overall are you happy with product? | Yes (3); | No (1) |

The above response is self explanatory and needs no further explanation. Indications are however, that the oven performs satisfactorily. There are problems such as smoke, and some complaints about the burning of the product which should be further investigated.

With regards to the savings made by the participants in using the oven, users number 1 to 4 made savings of 22, 24, 4 and 9 Leones per month respectively. (It should be noted that cost incurred for the sawdust was only for transportation). It is noted that participants 1 and 2, doing the daily commercial baking made the highest savings. Considering that the estimated cost of the oven is 650 Leones, this appliance has a potential for use in the country. Further attempts should be made to assess the viability of using less expensive construction materials such as bricks, so as to lower the capital cost of the oven.

## 7. CONCLUSIONS

A study has been carried out in which sawdust has been used to produce heat energy in an oven for domestic use. The conclusions which can be made are:

(a) An oven suitable for use in homes has been developed and fully tested.

(b) The temperatures which can be obtained in the oven by using combinations of the height of packing and number of holes in the burner, are comparable to those specified for conventional gas and oven cookers.

(c) Results of field tests indicate that the technical performance and product quality aspects of the oven are acceptable to the potential users, but the smoke produced during operation should be reduced.

(d) The oven costs less than 1/4 the price of a gas or electric oven and substantial fuel costs can be made with its use.

(e) The sawdust oven is a technology which should be encourage as it has a potential for use in small scale commercial baking.

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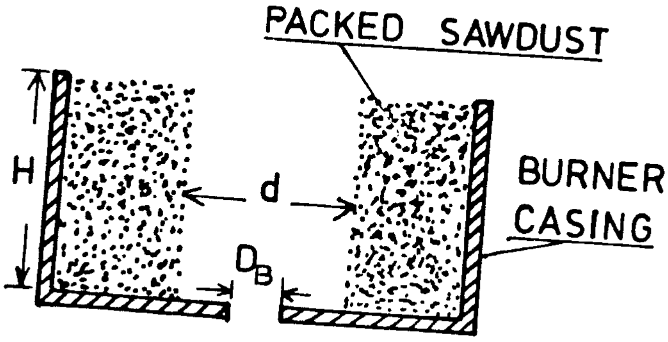
**NOTATION**

| | |
|---|---|
| $d$ | burner hole diameter, cm |
| $t$ | time, min |
| $D_B$ | air inlet hole diameter, cm |
| $m_f$ | mass of sawdust burnt in time t, gm |
| $H$ | height of packing of sawdust in burner, cm |




· Fig. 1 Schematic diagram of the hole-through-sawdust type burner with a single hole

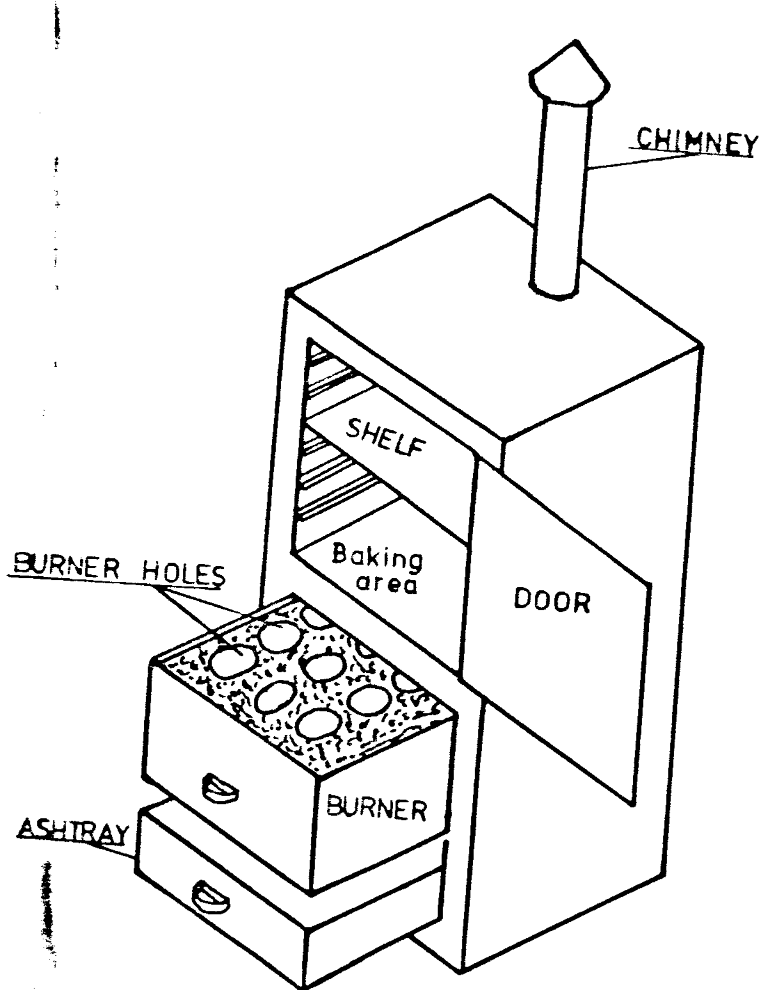



Fig. 2 Isometric view of ovens I and II

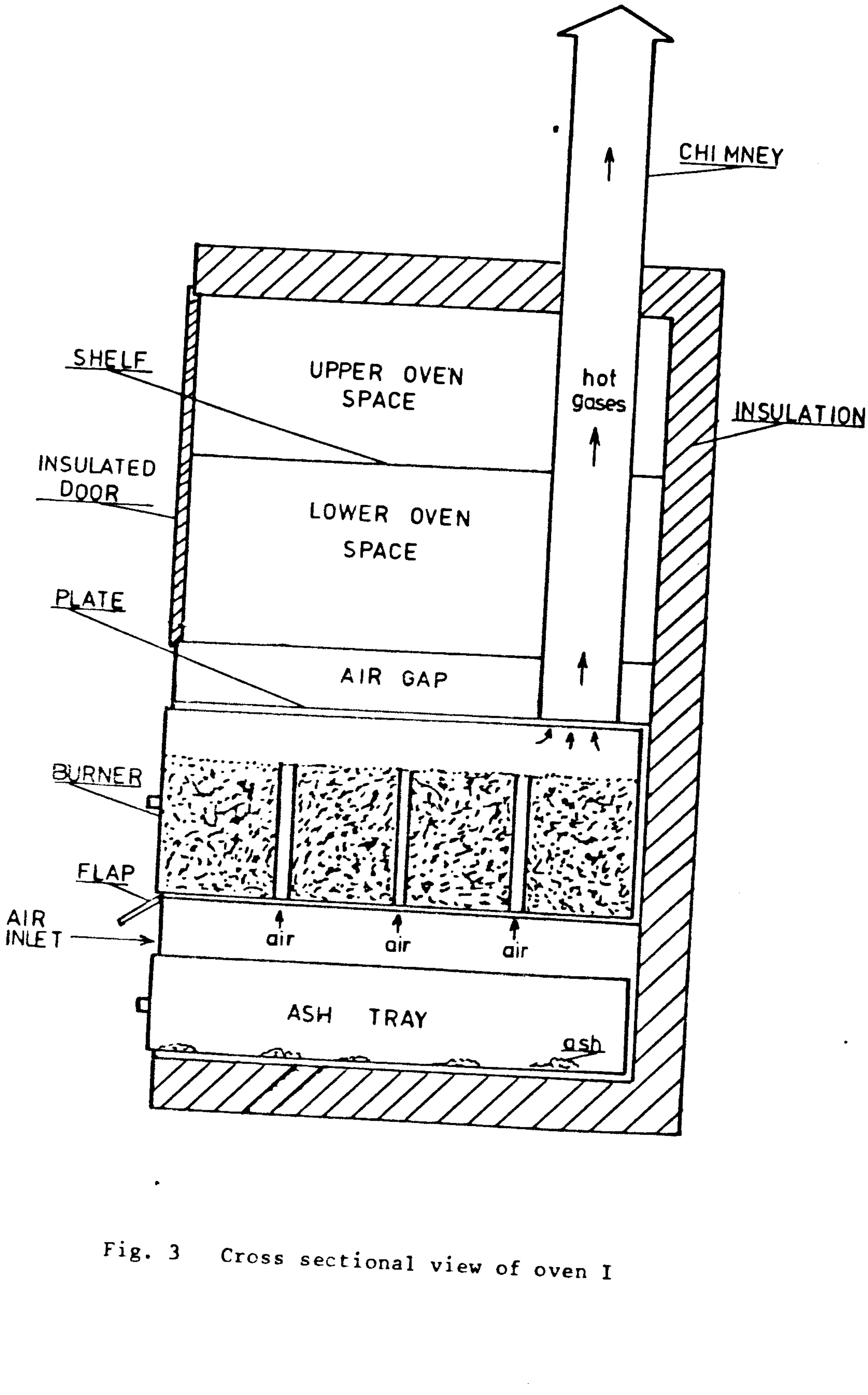



Fig. 3 Cross sectional view of oven I

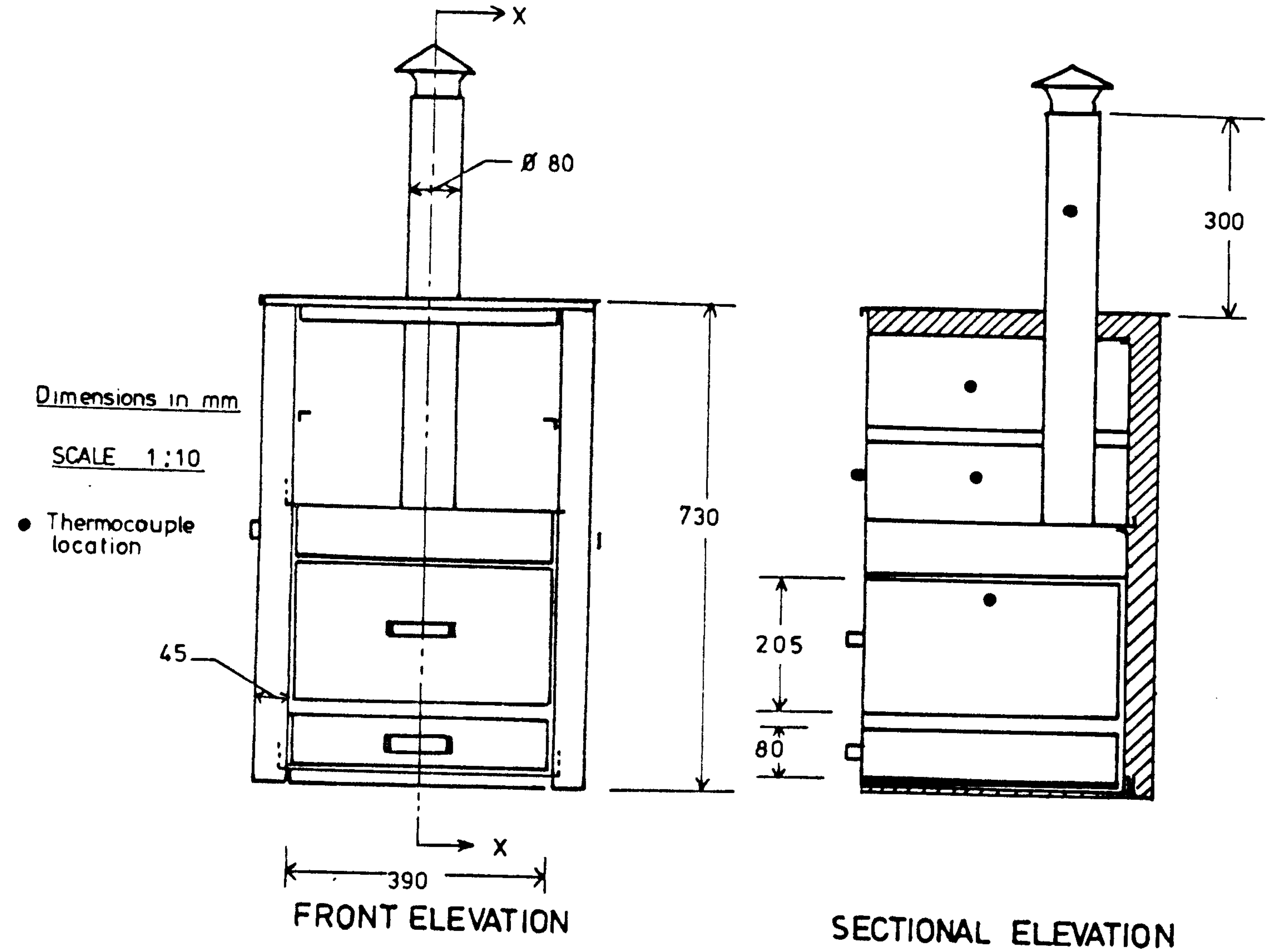



Fig. 4 Diagram of oven I showing relative dimensions

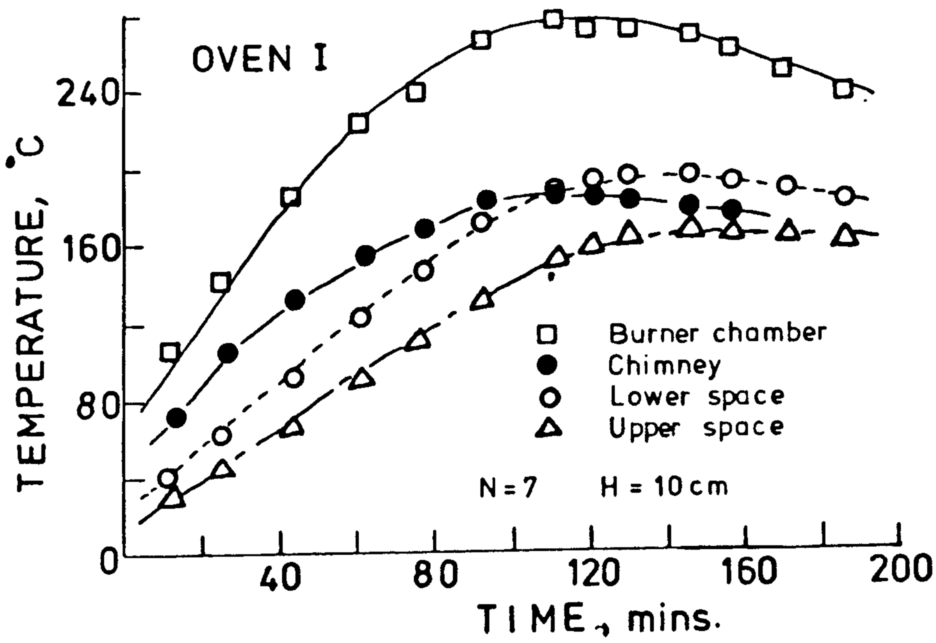



Fig. 5 Variation of temperatures in oven I with time, for H = 10 cm

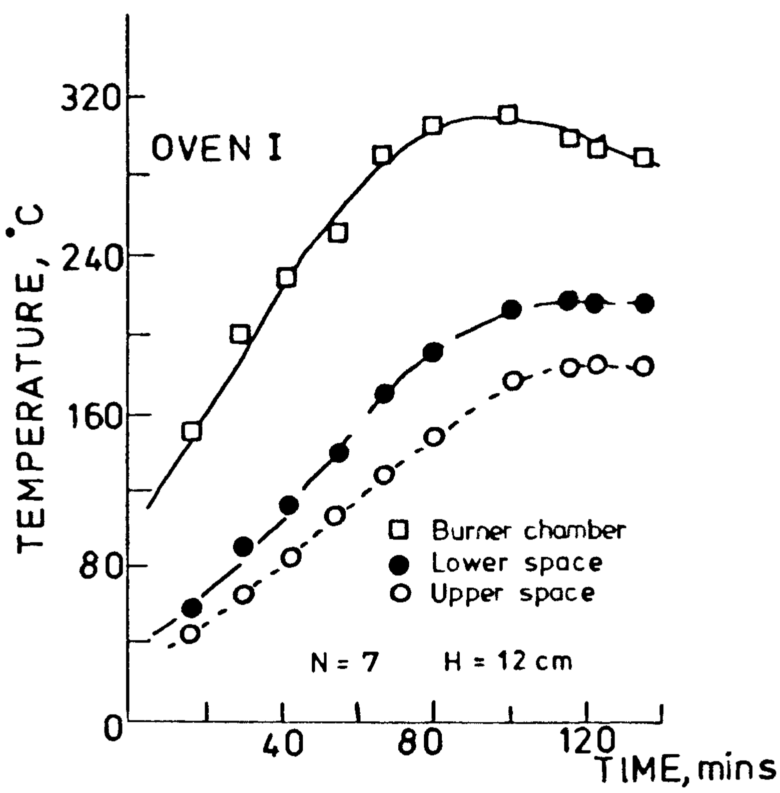



Fig. 6 Variation of temperature in oven I with time for H = 12 cm

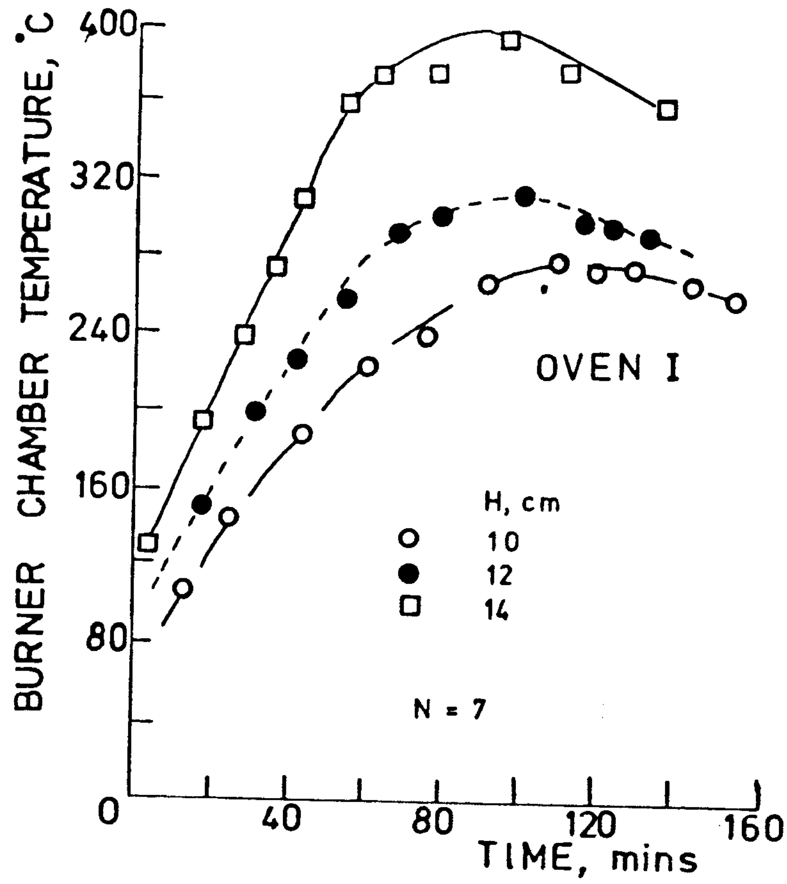



Fig. 7 Effect of increasing H on the burner chamber temperatures, for oven I

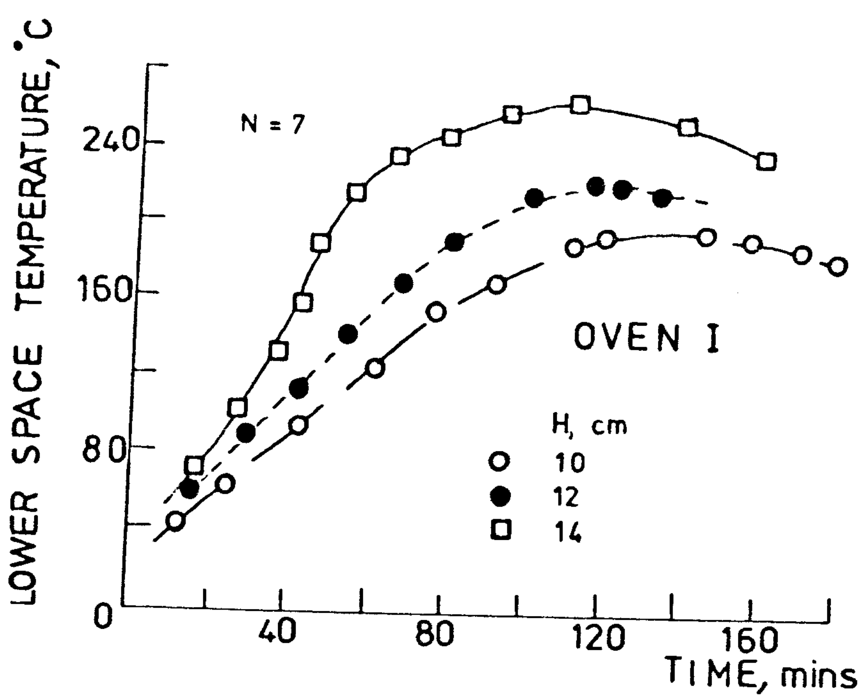



Fig. 8 Effect of increasing H on temperatures in the lower space, for oven I

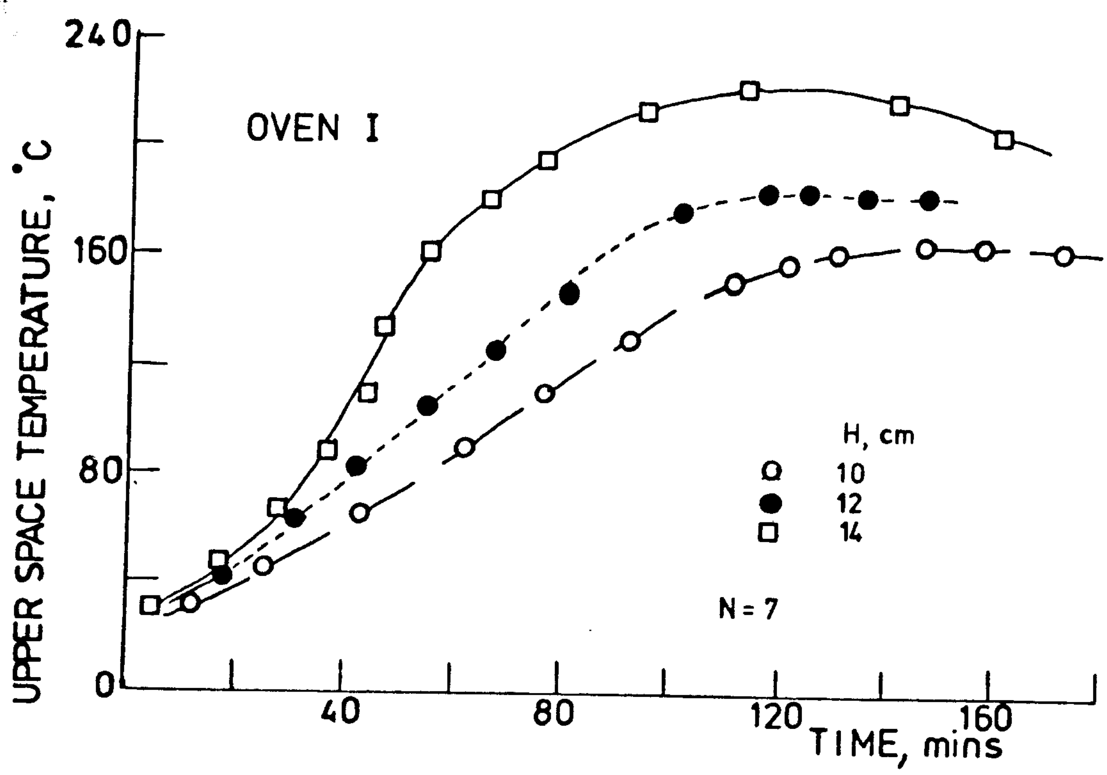



Fig. 9 Effect on increasing H on temperatures in the upper space for oven I

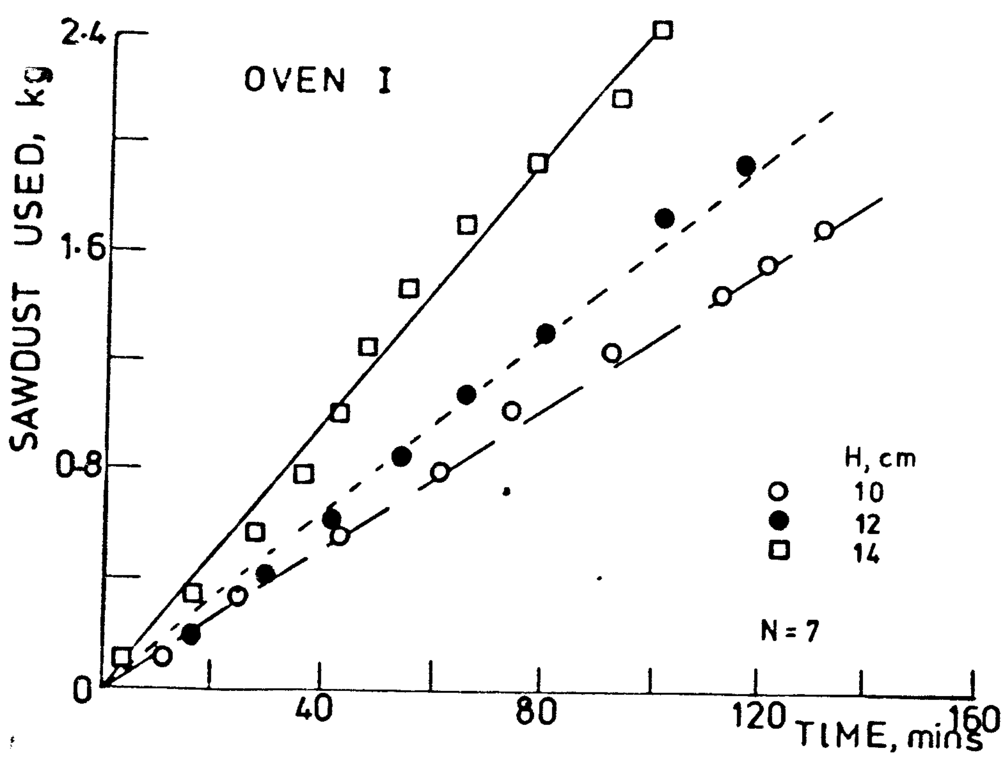



Fig. 10 Variation of mass of sawdust used with time for oven I

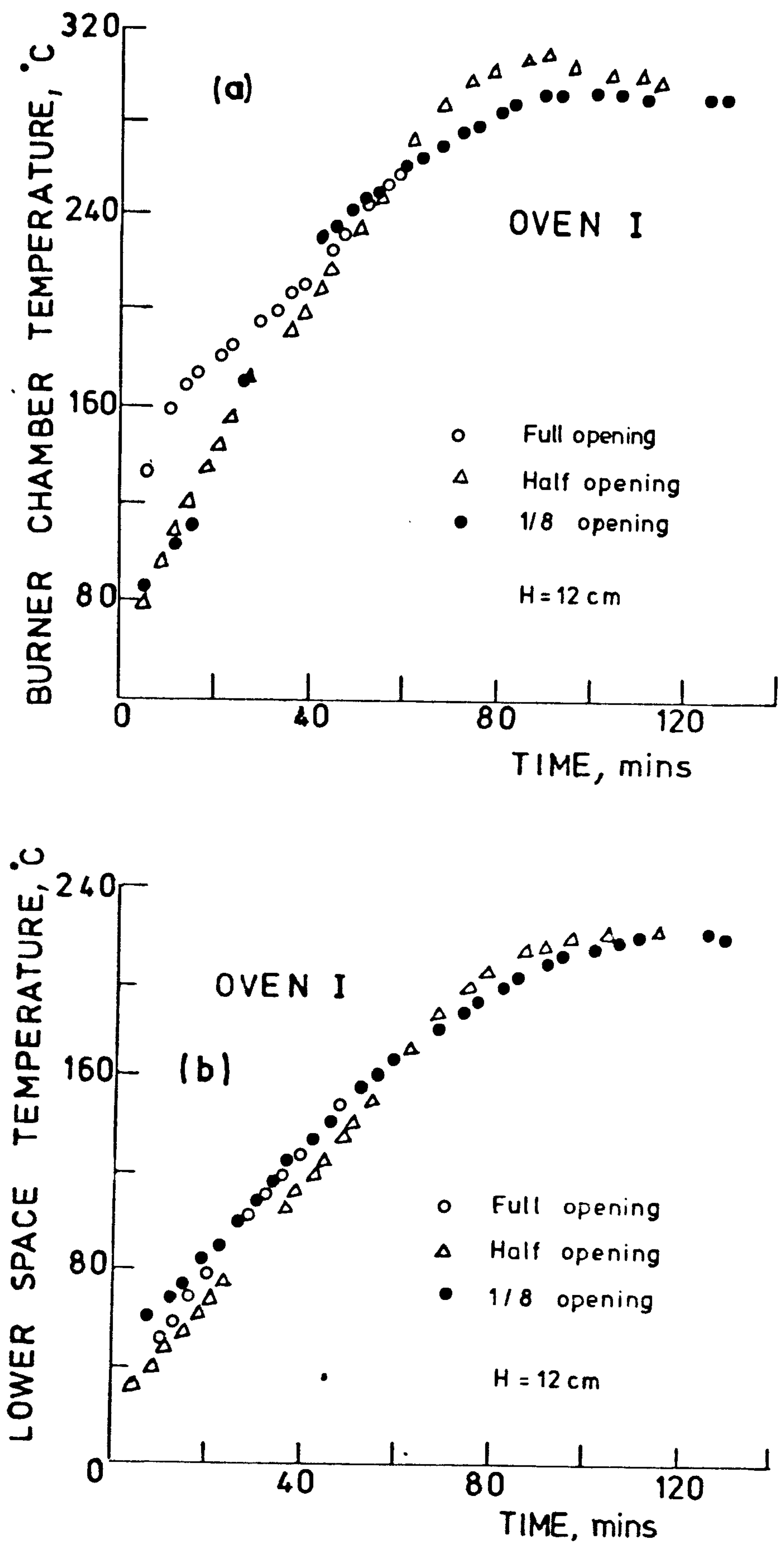



Fig. 11 Effect of damper setting on oven and burner chamber temperatures for oven I

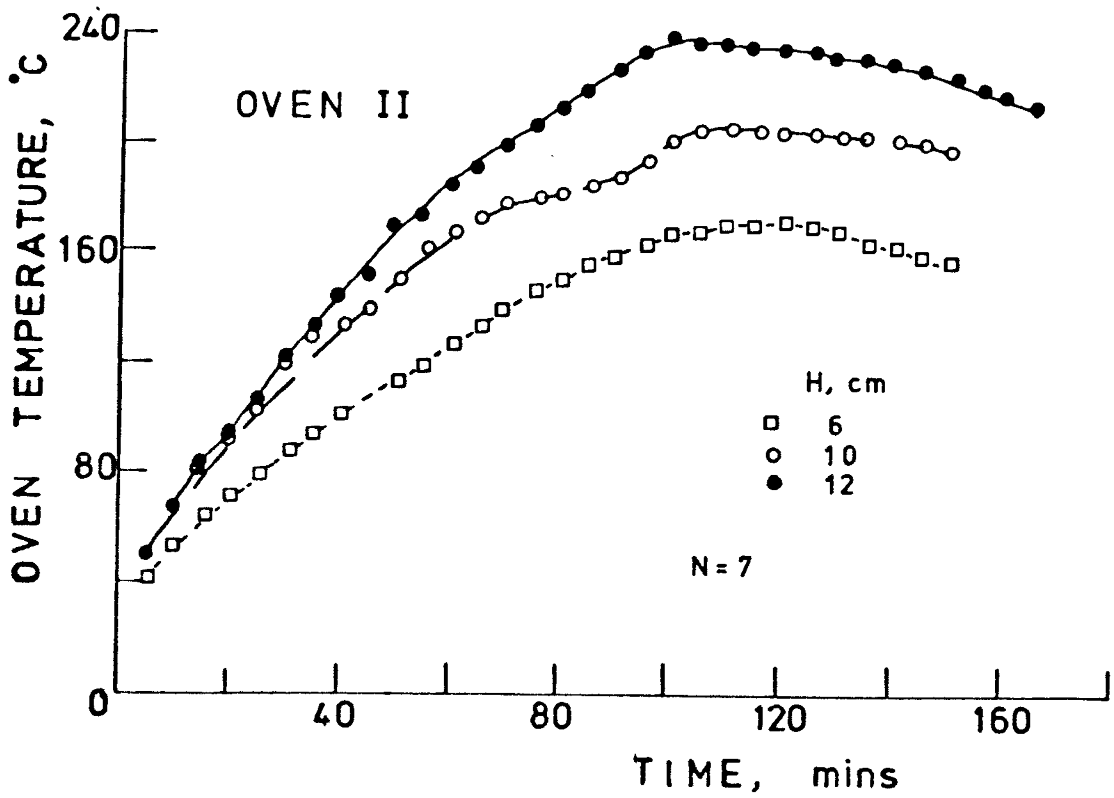



Fig. 12 Effect of increasing H on temperatures in the oven space for oven II